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Dixie Valley Remote Sensing Research
Overview: 1996 - 2002

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Introduction

- Work began in July, 1996
- Several remote sensing data types have been tested since to determine their value in geothermal exploration
  - Portable spectroradiometer
  - Thermal
  - Airborne hypsespectral

Objectives

- Main Objective: Test the usefulness of remote sensing as a tool for mapping hidden faults and blind geothermal systems – Dixie Valley is an excellent field laboratory

Objectives (cont)

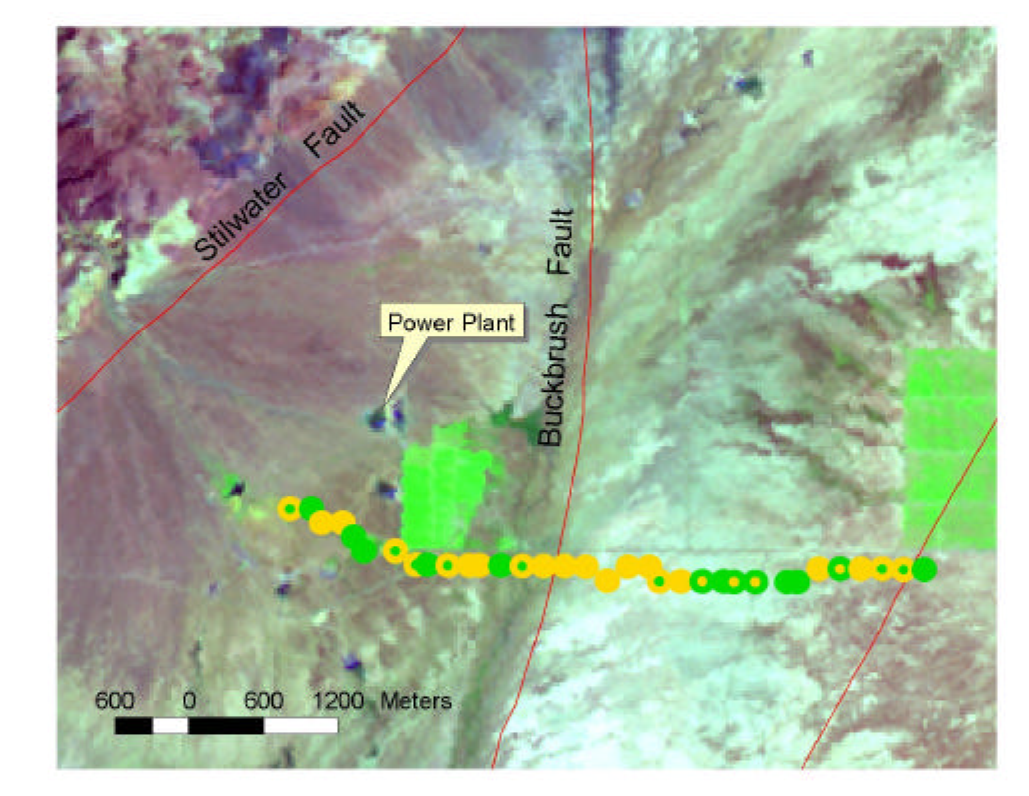
- Map geothermal system/structurally related
  - vegetation anomalies
  - soil mineralogy anomalies
  - thermal anomalies

- Develop data processing methodologies that can be used by industry to address exploration needs

In the Beginning

- Summer 1996: Vegetal-spectral analysis
  - Acquired greasewood field spectra
    - Transect planned based on soil geochemistry results of Hinke and Erdman (1995) and Hinkle, Briggs, Motooka, and Knight (1995)
    - Transect crossed a soil-geochemical anomaly across Buckbrush fault (branch)
    - 10 nm sampling interval: 400 – 1000 nm
    - 0.1 mile sample stations

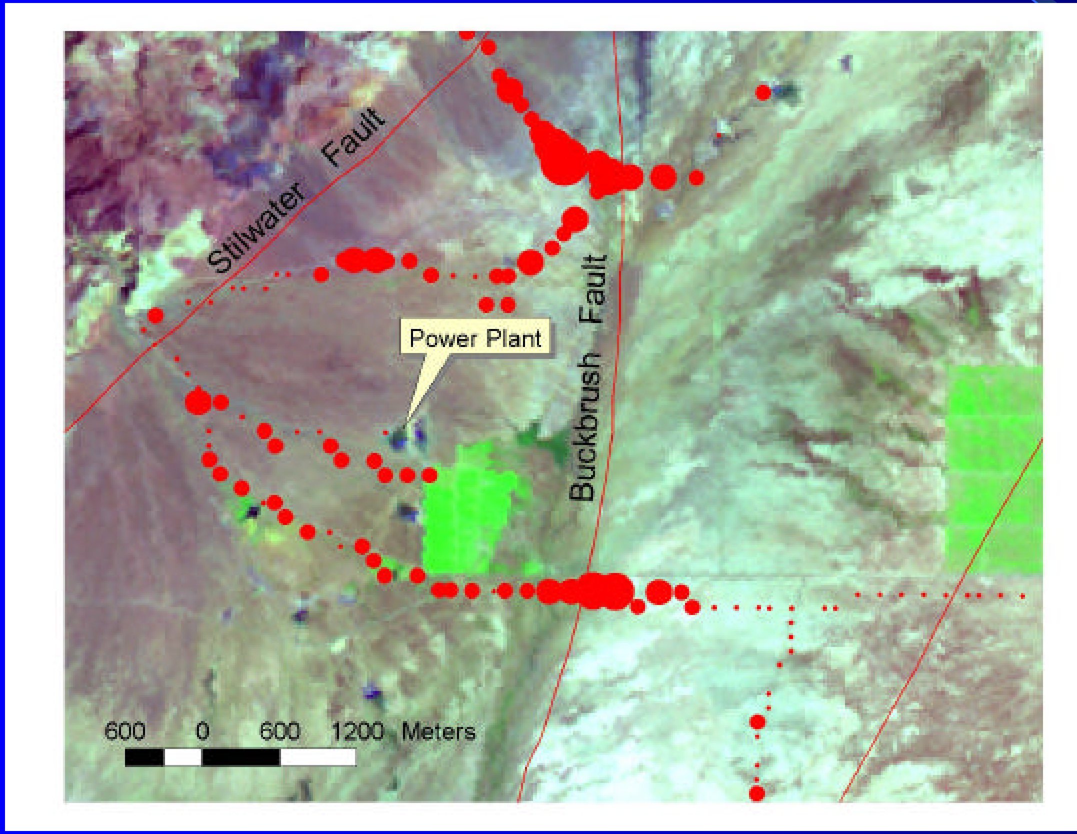
Big Greasewood Spectral Study



Spectra acquired in July, 1996 and June, 1997. Red-edge point of inflection used to indicate blue shifting. Consistent anomaly over Buckbrush fault.

1. Solid orange = consistent anomaly through time
2. Solid green = constantly healthy vegetation
3. Green on orange = healthy in June, but anomalous in July
4. Orange on Green = anomalous in June but not July.

Arsenic Concentrations
Hinkle et al.



A geochemical anomaly exits across the Buckbrush fault that is spatially correlative with the vegetal-spectral anomaly in the last slide.

Vegetal-spectral Analysis Conclusions

- A vegetal-spectral anomaly was detected
- The vegetal-spectral anomaly was spatially correlative with a soil-geochemical anomaly
- Both anomalies may or may not have been related to the Buckbrush fault and related mineralization
- Soil geochemical-anomaly may be from fluvial processes

Related Papers

- Nash, G. D. , 1997, Preliminary results from two spectral-geobotanical surveys over geothermal areas: Cove Fort-Sulphurdale, Utah and Dixie Valley, Nevada: Geothermal Resources Council Transactions, Vol. 21, p. 203-209.

- Nash, G. D., 1998, Seasonal variation in big greasewood spectral blue shifting, Dixie Valley, Nevada, *in* Federal Geothermal Research Program Update, fiscal year 1997, U. S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Geothermal Technologies.

A Major Vegetation Anomaly Appears

- On initial field visit (1996), Stu Johnson (Caithness) reported signs of vegetation stress near Senator Fumarole
- 1995 AVIRIS airborne hyperspectral data were ordered to facilitate study.
- Research focus changes to AVIRIS data analysis and interpretation

The Vegetation Anomaly Spreads

- By 1997 the anomaly had become readily apparent – Bailey's greasewood were dying over a relatively large area.

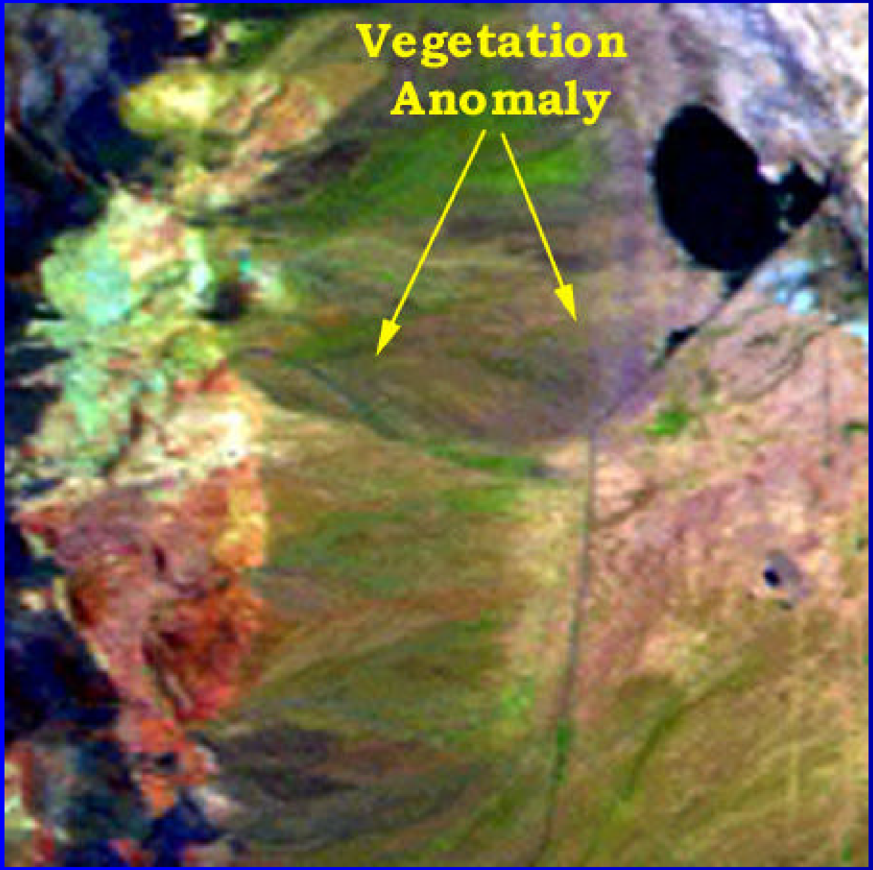
- Pre-anomaly AVIRIS data were tested to determine if early stages of vegetation stress could be detected.

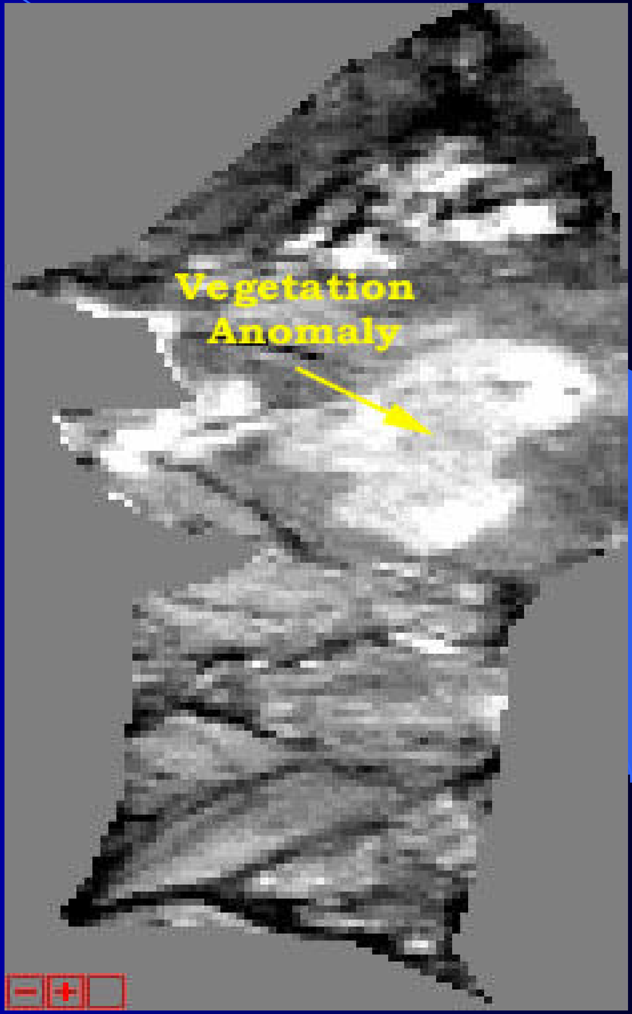
AVIRIS Data Processing

- Atmospheric Correction (ATREM)
- Spectral unmixing
  - Polytopic Vector Analysis
    - Defined anomaly
  - Principal Components
    - Defined anomaly
  - Mininum Noise Fraction
    - Defined anomaly

AVIRIS Data

Raw data (left) and Processed Data (right)





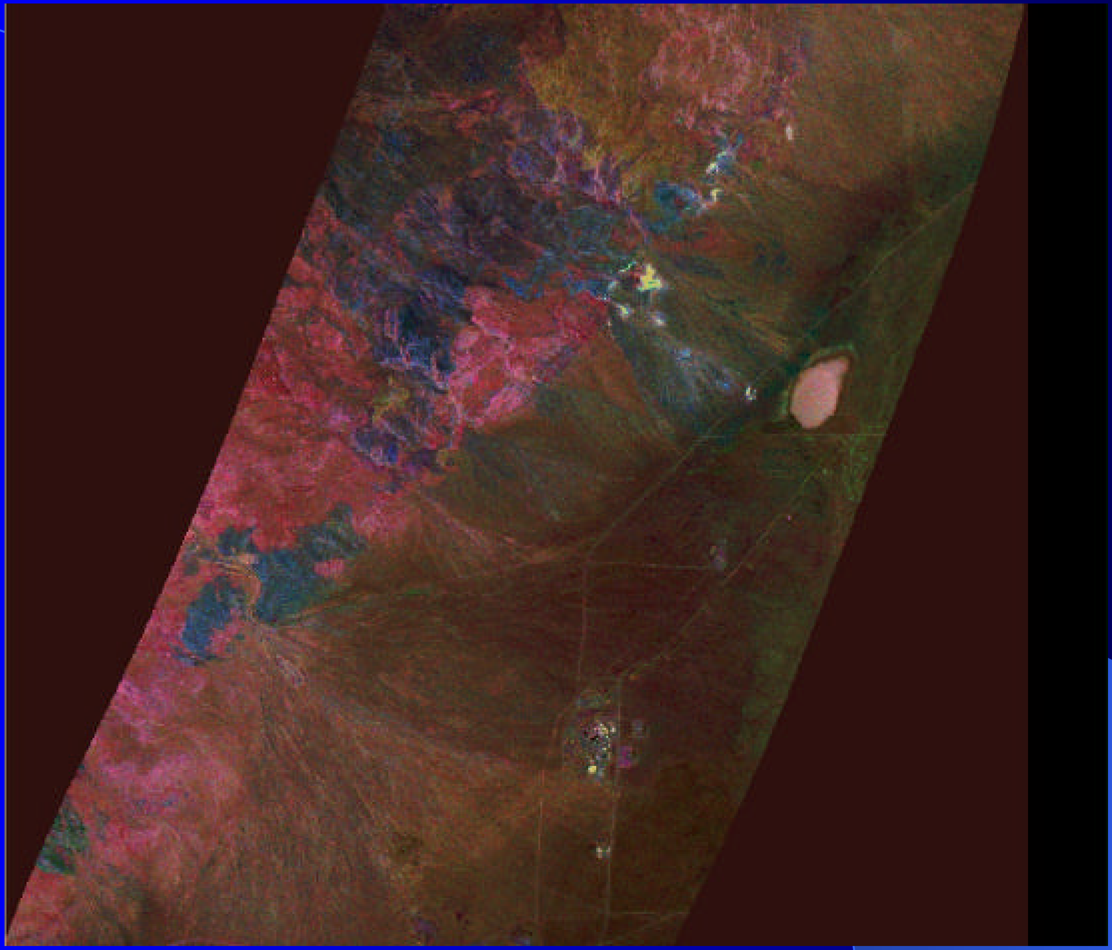
Vegetation Anomaly: Conclusions

- Related to production – reservoir pressure reduction caused boiling, degassing, thermal anomalies, and new fumaroles
- Geothermal related vegetal-spectral anomalies, both related to production and natural phenomena, can be detected using airborne hypespectral data. These data may be useful for exploration in vegetated areas
- Related Paper: Johnson, G. W. and G. D. Nash, 1998, Unmixing of AVIRIS hyperspectral data from Dixie Valley, Nevada, *in* Proceedings: Twenty-third Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California.

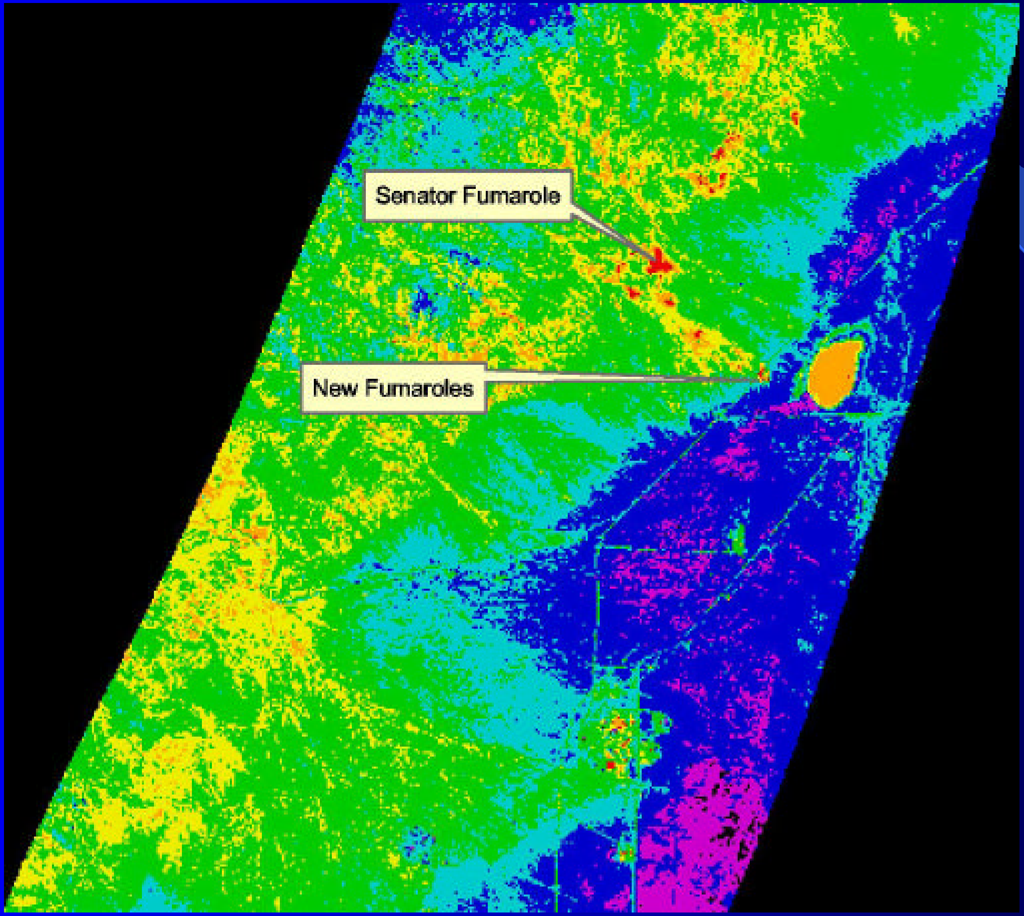
Thermal Data Analysis and Interpretation

- NASA ATLAS data acquired in July, 1998 (pre-dawn)
- Ground truth/temperature data collection performed in October, 1998
  - TIR sensor and thermistor used
  - Surface to 10 cm depth measured
  - Local temperatures measured to 1 m depth (near and at fumaroles at the toe of Senator Fan)
  - Temperatures corrected to flight time using data acquired on that date

Enhanced TIR Data
(light areas are thermal)



Relative Temperatures



TIR Interpretation and Conclusions

- Properly calibrated TIR data allows mapping surface temperatures
  - This data may be useful for heat flow mapping
- Relative temperatures are easily mapped showing thermal anomalies
- Valuable for mapping environmental base-line data
- Valuable for monitoring changes related to production

Related Papers

- Allis, R. G., S. Johnson, G. D. Nash, R. Benoit, 1999b, A model for the shallow thermal regime at Dixie Valley Geothermal Field, In Press, Geothermal Resources Council Transactions, vol. 23, 1999.
- Allis, R, G. Nash, S. Johnson, 1999, Conversion of thermal infrared surveys to heat flow: comparisons from Dixie Valley Geothermal Field, Nevada, and Wairakei, New Zealand, In Press, Geothermal Resources Council Transactions, vol. 23, 1999.

Current Research

- Soil mineralogy anomaly detection and mapping
  - AVIRIS hyperspectraal data used
    - Atmospheric correction
    - Unmixing (unsupervized and supervized)
  - Relative abundance mineralogy maps created
  - Soil mineralogy anomaly detected and mapped

Hydrothermal Convection Related Soil Mineralogy Anomalies: Requisite Conditions

- Reduced reservoir pressure - degassing
  - Production
    - Boiling
  - Seismic events
    - Boiling
  - Permeable structures
- Hydrothermally altered parent material
- Buried hot springs deposits

Data Processing - Goals

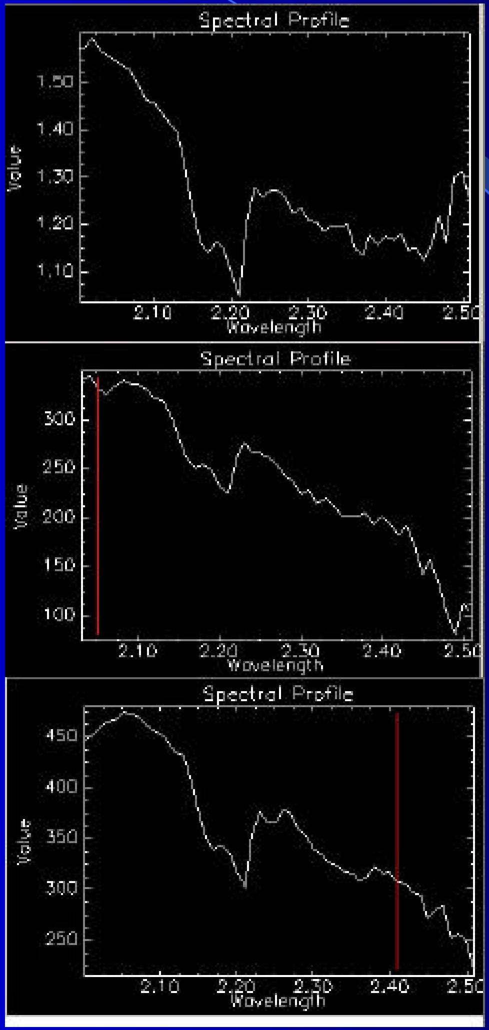
- Determine the number of contributing spectra
- Determine the spectrum of each source
- Determine the relative contribution of each spectrum in each pixel (spectral mixing proportions)

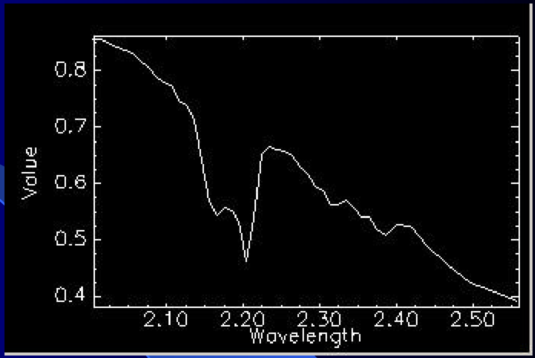
Data Preprocessing – Atmospheric Correction

- IAR Reflectance (internal average)
- Atmosphere REMoval Program - ATREM (based on radiative transfer modeling)
- Atmospheric CORection Now – ACORN (based on radiative transfer modeling)
- Data originally in radiance or digital numbers
  - Conversion to apparent reflectance

Examples of Atmospherically Corrected Data

- Three examples of a kaolinite apparent reflectance spectrum from a single pixel.
- Left
  - Top – IAR
  - Middle - ATREM
  - Bottom – ACORN
- Right
  - Lab Spectrum





Data Processing

Supervised Unmixing and Classification

- Methodology (ACORN processed data)
  - Minimum noise fraction (MNF) transformation
  - Pixel purity index (PPI) generation
  - Selection of mineral spectra end-members from the PPI;
  - Mixture tuned matched filtering (MTMF)
  - Color enhancement (optional).
- RSI – ENVI software used.

Supervised Data Classification: Results

- Four mineral end-members were quickly identified
  - Calcium carbonate
  - Chlorite
  - Kaolinite
  - Muscovite
- Calcium carbonate soil anomaly detected

Unsupervised (Self-Training) Mixing Model Polytopic Vector Analysis (PVA)

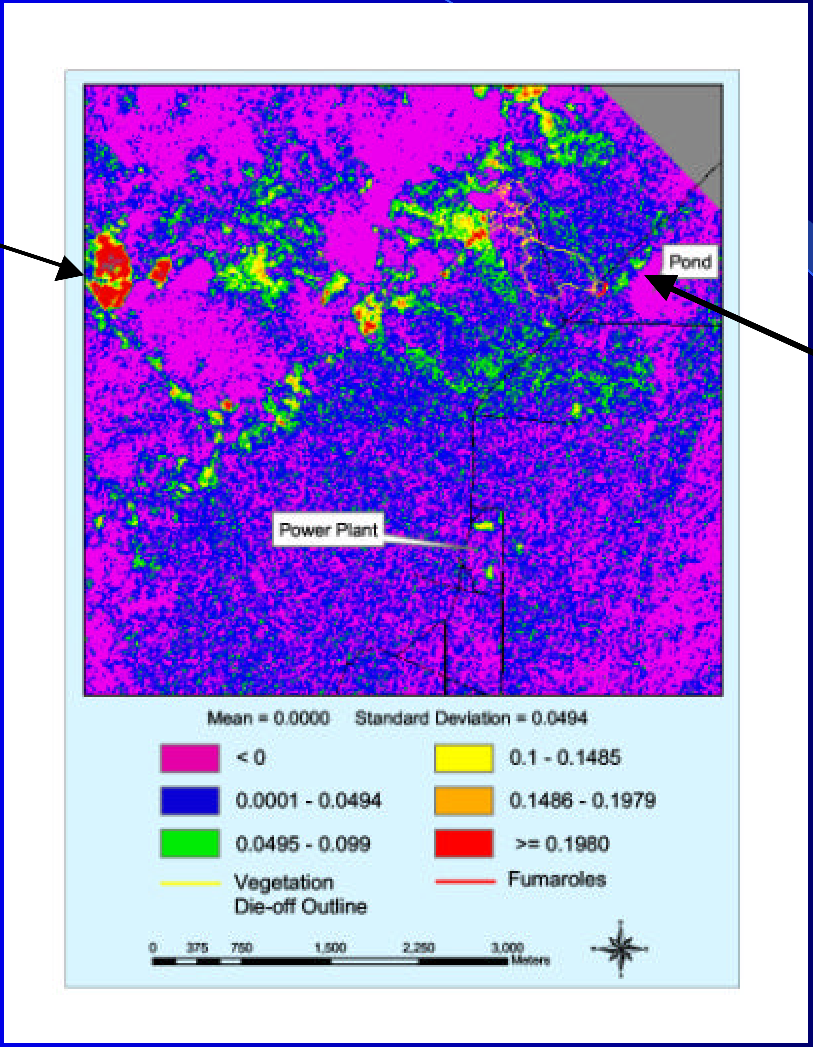
- PVA Attributes
  - Self-training (need not assume sources a priori)
  - Principal Components Analysis (PCA) based method
  - Quantitative source apportionment equations by development of oblique solutions in reduced PCA space
  - Explicit Non-negative constraints

PVA Model Results

- End-members were interpretable:
  - consistent with those chosen in the supervised method (kaolinite, chlorite, and muscovite)
  - Others consistent with water absorption and mafic minerals (olivine, hypersthene)
- Derived end-member spectra compared to published mineral spectra (Clark *et al*., 2000**)**
- Colinearity problem -- no calcite end-member

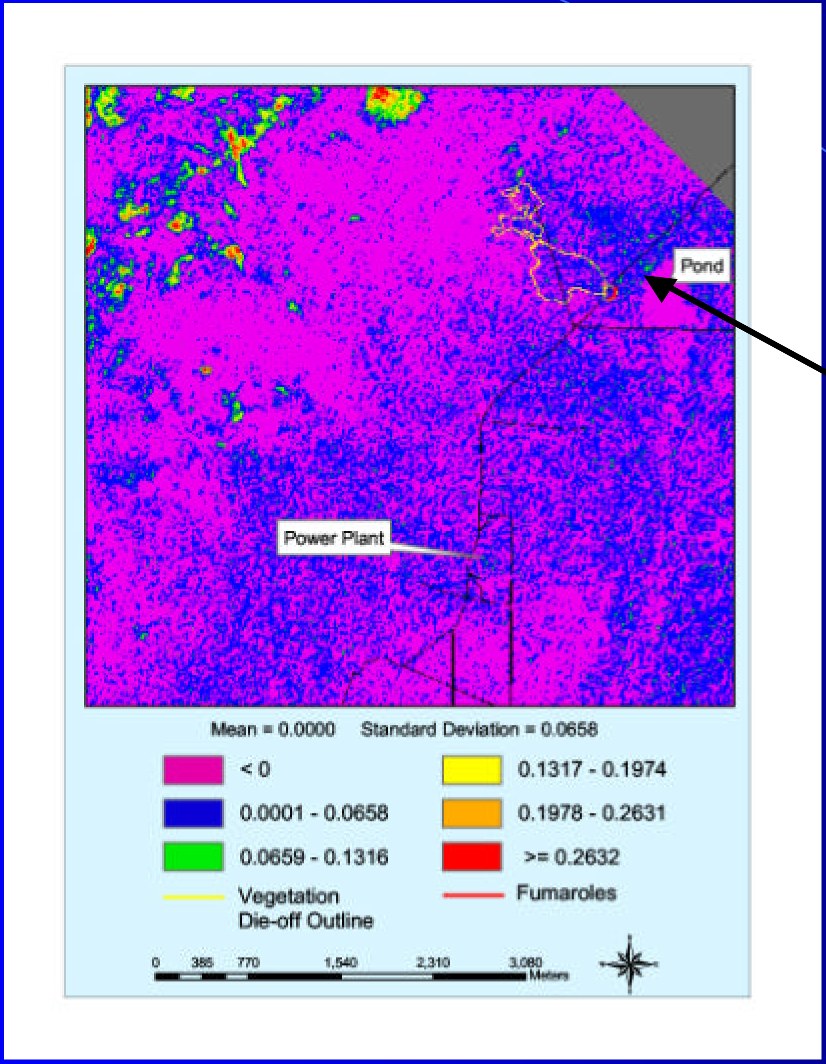
Calcium Carbonate Map

Hot springs travertine terraces in Cottonwood Canyon



Anomalous calcium carbonate concentrations located near new fumaroles. Moran's I = 0.017. Standard normal deviate = 1.29. Statistically significant on a one-tailed test at the 0.1 level.

Kaolinte Map



Kaolinite anomalies may also occur near the new fumaroles. However, they are not statistically significant.

Soil Mineral Anomaly Conclusions

- Geothermal system related soil mineralogy anomalies can occur from several sources
- These anomalies can be mapped using hyperspectral data and may be useful in identifying hidden structures and geothermal systems
- Field work is needed to provide ground truth to better determine source of calcium carbonate/kaolinte in the anomaly (to be done in June 2002)
- Related Paper: Nash, G. D., 2002, Soil Mineralogy Anomaly Detection in Dixie Valley, Nevada Using Hyperspectral Data, Proceedings: Twenty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 28-30, 2001, SGP-TR-171.

Plans and Acknowledgements

- New hyperspectral data is currently being acquired in the Dixie Meadows area. This will be used to aid in new well siting

- We would like to thank the Geothermal Energy Program, U.S. Department of Energy, for funding this research under contract **DE_FG07_00ID13958**

- **Papers and other data can be found at http://www5.egi.utah.edu or http://www.egi-geothermal.org**